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GEOLOGY OF A PORTION OF THE SOUTHERN COAST RANGES.[1]

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INTRODUCTION.

IT is the intention to present in the following paper a résumé of the most important results obtained during a detailed study of a portion of the southern Coast Ranges of California.

The area embraces about 570 square miles in the western part of San Luis Obispo county with the town of the same name nearly in the center. It has a length from north to south of thirty-five miles and an extreme width from east to west of twenty-nine miles. The seacoast traverses it diagonally forming the southwest boundary. The region is one of complex structural features and has represented within it nearly all the sedimentary formations characteristic of the Coast Ranges as well as a great variety of igneous rocks. As far as the writer has yet studied the Coast Ranges no other region of equal area has been found to contain so much of geologic interest.

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[1] Published by permission of the director of the United States Geological Survey.

More than six months of the past year has been devoted to field work[1] in this region besides several reconnoissances in former years. It is expected that a part of the results will appear in the form of a folio of the United States Geological Survey, and a complete report later in one of the Annuals.

TOPOGRAPHIC FEATURES.

The main topographic features have a northwesterly and southeasterly direction. The Santa Lucia is the highest and most important mountain range, extending parallel with the coast across the center of the area surveyed. On the south forming the high ridge terminating on the ocean in Point Buchon is the San Luis range. Crossing the northeast corner of the area is the northern extension of the San Jose range. All three ranges are traversed by narrow canyons which open upon broad and almost level or undulating valleys which extend in a northwest and southeast direction between these three important mountain blocks. The area is thus divided into two portions with sharply contrasted cycles of development, that is, recent mountain ranges with steep slopes and traversed by narrow canyons, and broad valleys in an advanced stage of base-leveling.

The Santa Lucia range forms the divide between those streams which flow directly into the Pacific Ocean and those which drain into the Salinas River. The valley of the upper portion of this river crosses the region surveyed between the

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[1] The writer was aided in the field by Mr. F. E. Harvey, a senior student in Stanford University, and Mr. Robert Moran of San Luis Obispo, both enthusiastic students.

Santa Lucia and San Jose ranges. South of the Santa Lucia, between it and the San Luis range, are the broad and fertile San Luis and Los Osos valleys opening northwestward to Morro Bay. A series of sharp peaks extends from a point a little south of the town of San Luis Obispo northwest to Morro Rock separating these valleys from the foothills of the Santa Lucia range.

The Santa Lucia range as far as its recent movements are concerned forms a geological unit, and viewed from the south it presents a bold and comparatively regular front and even sky line. The highest portion has an elevation of nearly 3000 feet, and the summit a width of two to four miles. The topography of this range while presenting certain common features yet varies greatly in different portions, owing to the marked variation in resistency offered to erosion by the different geological formations. The Monteveys hales, which are mostly confined to that portion east of Cuesta Pass, are cut by deep V-shaped canyons while northwest of this pass the soft Knoxville shales, extending longitudinally through the centre of the range, exhibit a succession of open valleys.

The granite mountains (San Jose range) in the northeastern corner of the area surveyed reach an elevation of nearly 2000 feet, but do not seem so high because of the elevated valleys about them. They are cut by narrow canyons, but do not rise as abruptly from the adjoining valleys as the Santa Lucia range. This elevation of land is a magnificent example of an ancient base leveled mountain range. Viewed from most any point along the foothills of the Santa Lucia range the numerous furrowed ridges fall into an even sky line many miles long.

The San Luis range attains an elevation of a little over 1800 feet. It consists of a series of sharp ridges traversed by deep narrow canyons. To the east it lessens in height and finally blends with the Santa Lucia range.

The line of buttes extending from the vicinity of San Luis Obispo northwestward and terminating in Morro Rock constitutes the most remarkable scenic feature in the landscape. The buttes rise from 400 to 1500 feet from open valleys which are but little elevated above tide level, and terminate in Morro Rock which rises out of the ocean to a height of nearly 600 feet. These are undoubtedly peaks of erosion, the hard crystalline rock of which they are composed weathering away much more slowly than the soft strata of the Golden Gate series in which they were intruded.

The extensive valleys south of the Santa Lucia range are underlaid by the oldest sedimentary rocks (Golden Gate series) of the sheet and are, in their general features, of great antiquity compared with the abrupt mountain ranges on either hand. The valley block has acted practically as a unit since the period of disturbance giving rise to the Santa Lucia and Buchon ranges.

The principal hydrographic basin is that of the Salinas. This stream flowing across the northeast corner of the area pursues a comparatively regular course until it empties into Monterey Bay. The remarkable thing, however, about the river is, that instead of flowing in the lowest depression between the Santa Lucia range and the granite mountains, it has cut a channel for a number of miles through the granite flowing in a canyon 500 to 700 feet deep.[1] Its meandering course brings it in places to the edge of the granite, where it receives tributary streams from the Santa Lucia. These transverse streams have so eroded their separating divides in the soft sandstones between the two ranges that they form an almost continuous valley which is strictly a continuation of the valley of the Salinas farther down. This is clearly a case of superimposed drainage, for when the course of the Salinas and its tributaries was originally outlined the present valley region must have been higher than the granite ridge.

A similar superimposed drainage is to be observed in the case of the streams which flow southwesterly from the Santa Lucia range. These traverse the broad open stretches of the San Luis valley, which in its lower portion is not over 200 feet above the sea, and separated from Los Osos valley by a divide not 50 feet high, and then pass directly into the San Luis range, cutting across it in narrow canyons at right angles to its course for a distance of over three miles. The most westerly of these streams, the San Luis Creek, has cut through where the range is 1000 feet high ; and the other, Pismo Creek, traverses it where it is but little lower. The watershed between these streams has almost disappeared, and but little change in the topography would cause the whole drainage to pass westward along the northern slope of the San Luis range to Morro Bay. When the courses of these streams were originally outlined the San Luis range probably did not exist, and the general slope of the country was southwesterly. With the beginning of the upward movement along the axis of the range erosion continued to be rapid enough so that the original drainage was maintained.

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[1] JOUR. GEOL., Vol. V, p. 576.

SEDIMENTARY TERRANES.

An almost continuous series of sediments from the Middle Mesozoic down to the present is represented in different portions of the central and southern Coast Ranges, but owing to the oft repeated mountain-making disturbances the series is not complete at any one spot. Except for the absence of the Horsetown beds, the Eocene, and possibly the marine Pliocene, the series is practically complete in the region under discussion.

In the northern portion of the Santa Lucia range and other portions of the Coast Ranges there is still an older series of sedimentary rocks which are of unknown age, but were involved in the granite magma at the time of its formation and now appear as marbles, schists, etc. All that is known about these rocks is that they are older than the granite, and that the granite itself is much older than the Golden Gate series (Jurassic) which rests upon it with a basal conglomerate. None of these metamorphic rocks appear associated with the granite north of the upper Salinas River, although farther northwest along the same crystalline axis they are extensively developed.

JURASSIC PERIOD.

Golden Gate series. — This series forms the base of the unaltered sedimentary rocks in the central and southern Coast Ranges. The exact position of these rocks in the geologic scale remained a puzzle to geologists for many years, partly because of the scarcity of fossils, and partly because of the obscure stratigraphic relations.

In former papers[1] the writer has advanced considerations for the belief in the pre-Cretaceous age of this series of rocks, and that it underlies the Knoxville unconformably. In later papers[2] the series was named and more definite proofs given of its relation to the Knoxville. During the recent detailed study of the region about San Luis Obispo the question was conclusively settled in favor of the position maintained by the writer. Two lines of evidence aided in the determination. The first concerns the relation of the series to the Knoxville. Both of these groups of rocks are extensively developed in the region in question, each with its characteristic features. The Golden Gate series is most largely exposed along the southern slope of the Santa Lucia range, in the large valleys at its base, and on the northern slope of the San Luis range. A narrow strip also occurs on the northern side of the Santa Lucia range, exposed through faulting. The Knoxville beds begin as scattered outcrops on the southern slope of the Santa Lucia range east of the town of San Luis Obispo and extending northwest through the depression in the range known as Cuesta Pass, expand to form many square miles of mountainous country through the heart of the range. At numerous points on the northern slope of the range, from the Eagle Ranch to the head of Morro Creek, were found patches of the basal Knoxville conglomerate, either resting upon the upturned Golden Gate series, or upturned itself and faulted down into the latter series. Specimens of Aucella were found in strata of sandstone and fine conglomerate within four feet of the base of the beds. Near the road, two miles northeast of San Louis Obispo, the base of the Knoxville beds is exposed on a little hill. It consists of conglomerate, perhaps thirty feet thick, and dips easterly at a low angle. Exposed on either side of the hill and passing through under the conglomerate is one of the pre-Cretaceous basic intrusives similar to others near by in the Golden Gate series. This must have been the old sea bottom on which the conglomerate was deposited. In Reservoir Canyon, a little more than a mile southeast of this locality, is a hill about one-half mile in diameter formed of Knoxville shales and one thin layer of conglomerate. The shales are but little inclined and are underlaid and surrounded on all sides by the upturned and nearly vertical sandstones and associated intrusives of the Golden Gate series. Perfectly preserved specimens of *Aucella* were obtained from a concretionary nodule at the very base of the Knoxville on the south side of the hill.

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[1] Am. Geol., Vol. IX, p. 153; Am. Geol., Vol. XI, p. 70; Bull. Geol. Soc. Am., Vol. VI, p. 71.

[2] JOUR. GEOL., Vol. III, p. 415; Am. Geol., Vol. XVIII, p. 350.

The second line of evidence, that of palæontology, leads to the conclusion that the series is not older than the Jurassic, the radiolaria as well as the molluscan remains both agreeing upon this point. All the specimens of the latter so far obtained from the series are probably new species and appear to be indeterminate as far as the question of Jurassic or Cretaceous age is concerned. Only one locality of mulluscan fossils was discovered and that is located on the coast, six miles north of Port Harford. A small species of a pecten-like form occurs in great abundance here through a thickness of about eighty feet of black slate which stands vertical and is inclosed between dikes of diabase.

The strata of the Golden Gate series consist of sandstone which forms fully four-fifths of the whole, numerous lenticular beds of radiolarian jasper, shale, and a little conglomerate. The whole has been upturned, folded, and faulted in a very complex manner and intruded at various periods by dikes of igneous rocks in great variety and abundance. The different members of this series have the same character as in other portions of the Coast Ranges where they have been described.[1]

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[1] Bull. Geol. Soc. of Am., Vol. VI, p. 82; U. S. Geol. Sur., XVth Annual Report, p. 415.

The sandstone is characteristically thick bedded and in general shows little if any metamorphism, except in the vicinity of eruptive masses. It disintegrates readily, forming a rather heavy soil. It is almost everywhere, however, seamed and fissured, while the softer, shaly strata are often crushed and distorted. The five-mile section along the coast, north of Port Harford, exhibits the relative proportion of sandstone in the series. Along this stretch the strata stand vertical and with the exception of thin layers of shale and several lenticular strata of jasper consists entirely of sandstone. The apparent thickness of this section is fully 10,000 feet, but whether this represents the total thickness of the Golden Gate series is not certain.

The outcrops of jasper are very abundant over the whole of the region occupied by the Golden Gate series, and as they weather away much more slowly than the sandstones form the most prominent of the smaller topographic features, rising often as jagged or rounded knobs above the rolling contour of the hills. There are at least half a dozen important horizons, which, though apparently not confined to any one portion of the series yet are mostly aggregated toward what seems to be the basal portion. The strata of jasper are of very irregular dimensions swelling and pinching and often appearing as isolated lenses, but rarely exceeding 100 feet in thickness. The basic intrusives so numerous in the Golden Gate series occur mostly in that portion occupied by the jasper beds, the latter generally being reddened and .often involved in the erupted masses. The contact of the jasper with the sandstone as well as the easy parting of the jasper bands undoubtedly facilitated the passage of the molten matter. The organic nature of the rock is indicated by the minute radiolarian skeletons in which the structure can often be seen with a pocket lense.

Scattered over the area occupied by the Golden Gate series occur prominent outcrops of a metamorphic schistose rock having a predominantly bluish tint. Owing to the general covering of soil the relations of these rocks are not always shown but where exposures are sufficiently good they appear to be bunch-like or eliptical in form, sometimes 100 feet thick and several hundred feet long, and from this size down to those only a few inches in thickness. Where the inclosing rocks are exposed they invariably lie in contact with one of the fine grained basaltic intrusives. Glaucophane gives the characteristic bluish tint, but other minerals, such as a pearly mica, chlorite, quartz and garnet occur. These rocks possess great interest though the problems connected with their occurrence are not yet all solved. There can be little question that they have been formed through the metamorphosis of argillaceous strata in contact with igneous masses, but why this action was so irregular and intermittant it is difficult to comprehend. It is also puzzling to know why the contact rocks are invariably associated with a certain type of the pre-Cretaceous basic intrusives and not with others, such as the peridotites. The exceeding abundance of the contact rocks through those areas of the Golden Gate series where the old eruptives are the most numerous, indicates plainly that the most if not all the latter are of subsequent origin.

CRETACEOUS PERIOD.

Knoxville Beds.—The rocks of lower Cretaceous age are now confined to the Santa Lucia range, although once probably much more extensive. They form an almost continuous strip from the head of the Corral de Piedra Creek on the south slope of the Santa Lucia range northwest for a distance of over twenty miles. North of Cuesta Pass they widen out forming for a number of miles nearly the whole of the brush-covered mountains between the two crests of the range. The structure of this portion is synclinal and seems to be due to the intrusion of great masses of diabase along its edges and which form the double crests referred to. The beds are perhaps 3000 feet thick and consist of dark shales and thin bedded sandstones closely resembling those of the same age in other parts of the state. Several thin layers of pebbly conglomerate occur, one being at the base and containing numerous pebbles of jasper and other silicious rocks.

The genus *Aucella* is well represented through the lower and middle portion of the shales, but the upper portion appears to be barren of life.

The nonconformity with the underlying Golden Gate series is most marked, not only by the discordance in dip but through much less distortion of the upper beds and the entire absence of the intrusives so characteristic of the lower series. Although so much evidence exists of a break between these two groups of rocks, its real magnitude does not yet seem to be appreciated by geologists as it ought. The more the question is studied the more its importance must appeal to geologists.

Chico formation.— The upper portion of the Shasta group known as the Horsetown beds was not recognized within the area under discussion and it seems probable from the stratigraphic relations existing between the Knoxville beds and the Chico formation that it is absent. The Chico occurs in two widely separated localities. The most important one forms a belt one to two miles wide and many miles long on the northern slope of the Santa Lucia range. The other is a strip about the same width extending along the coast from a point six miles west of Cayucos, northwestward for about eighteen miles. In both areas the rock consists almost wholly of sandstone. Fossils are not abundant but they were found in sufficient numbers in the Santa Lucia Mountains to demonstrate the age of the formation. In the latter locality the sandstone terminates downward in a conglomerate which is in places 100 feet thick, resting either upon the Knoxville shales or the Golden Gate series. The sandstones on the coast rest upon the Golden Gate series exclusively. The relation to the Knoxville shales was carefully examined at many points along the northern slope of the Santa Lucia Mountains and a conclusion reached which is in accord with one already published,[1] namely, that the lower and upper Cretaceous are, in this region at least, separated by a nonconformity. This is shown by the marked discordance in the dip between the two and the extension of the upper across the strike of the lower, as well as by the fact that the upper rests indiscriminately upon either the lower Cretaceous or the Golden Gate series. A nonconformity is also indicated by the fact that where the serpentine in this region, as in other portions of the Coast Ranges, comes in contact with the lower Cretaceous, the relation is one of intrusion while the Chico rests upon it undisturbed. The lower Cretaceous was intruded by the peridotite, upturned and eroded before the deposition of the Chico.

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[1] JOUR. GEOL., Vol. III, p. 426.

TERTIARY PERIOD.

Strata of Middle Tertiary age are widely distributed over this region and probably once covered nearly the whole of it. The Eocene on the contrary is entirely absent although extensively developed to the southeast in Santa Barbara and Ventura counties. It seems probable that during early Tertiary time this portion of the Coast Ranges was above water for if the Eocene ever had existed here it would be reasonable to expect some remnant of it would be met with. The Lower, Middle, and Upper Neocene are all represented.

NEOCENE.

Monterey series (*Lower Neocene*).—With the beginning of the Neocene a subsidance commenced and continued through, or nearly through the Miocene. Finally, almost the whole Coast Range region was submerged and a thickness of rocks in many places of more than 7000 feet was deposited. The most characteristic feature of the series is the bituminous shales. They form its upper portion and reach a thickness of 5000 feet. Below them are limestones, clays, volcanic ash, sandstones and conglomerates. Erosion has removed a large part of these rocks, but the similarity in succession of the characteristic horizons at various points in the area surveyed points to the fact of their former continuity.

The sandstones and conglomerates at the bottom of the series are most prominently developed in the region lying east of the Rinconada Valley, between it and the main granite range.

The thickness of these beds is remarkable, being 6000 to 8000 feet. They occupy the same position with reference to the bituminous shales as similar beds on the upper San Antonio River.

The volcanic ash forms a fairly constant horizon over nearly the whole of the region mapped. Several different centers of volcanic action seem to have existed in this region shortly after the beginning of the Miocene. In the mountains south of San Luis Obispo the ash has a thickness of fully 800 feet, while beginning near the Lion rock at the western end of the San Luis range this bed of volcanic ash extends easterly along the southern slope for a distance of over thirty miles. Near the centers of eruption the fragments are coarse, but farther away the deposit consists of frothy pumice, and in places occurring in beds of glass as fine as dust. On Old creek a small flow of banded rhyolite is associated with the fragmental material. It seems probable from the large amount of ash and small amount of massive lava that the eruptions were of an explosive nature and took place at or beneath the surface of the sea. This is the same eruption as that indicated at Point Sal.[1]

The bituminous shales and flints form the uppermost member of the Monterey series. They constitute the main portion of the San Luis range and that portion of the Santa Lucia range lying east of Cuesta Pass. They also underlie the younger formations in the upper Salinas Valley. This formation measured in both ranges appears to reach the enormous thickness of 5000 feet. It consists almost exclusively of a thin banded silicious shale which over extensive areas has been changed to a flint. Much remains to be done in a detailed study of these shales, although it has been quite certainly proved that they are largely of organic origin.[2] The shales are generally more or less impregnated with bituminous matter, and it appears to be reasonably certain that they constitute the main source of the oil and asphaltum which is so widely distributed through the Coast Ranges. Springs of thick oil and sulphurous water issue from them, and when covered by porous beds vast deposits of bitumen have been formed.

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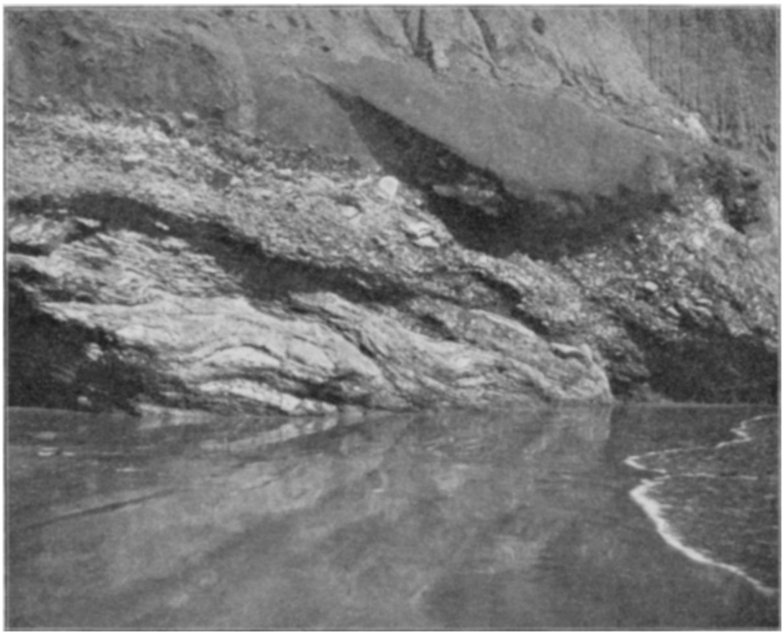
[1] Bull. Dept. of Geol., University of California, Vol. II, p. 16.

[2] Bull. Dept. of Geol., University of California, Vol. II, p. 13.

San Pablo formation (*Middle Neocene*).—Overlying the Monterey series unconformably is a series of soft sandstones, diatomaceous beds, and some flinty shales. It forms the eastern extension of the San Luis range between San Luis Obispo and the ocean, as well as a considerable area in the upper Salinas Valley. In the latter region it is filled with fossils which indicate the Middle Neocene, but to be more exact, whether the uppermost Miocene or the lowest Pliocene is as yet undetermined. Dr. Merriam has in a recent publication[1] described a series of strata on the southern shore of San Pablo Bay containing a similar fauna which he believes represents a distinct and



Nonconformity between the San Pablo formation and the Monterey series. Ocean cliffs near Pismo.

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[1] Bull. Dept. of Geol., University of California, Vol. II, No. 4.

hitherto unrecognized palæontologic group. These strata it appears overlie those of the Contra Costa county Miocene with indications of a nonconformity, but the fossils collected from them by earlier palæontologists have in some cases been referred to the Miocene, in others to the Pliocene. To this series of rocks Dr. Merriam has given the name San Pablo formation. As the group of rocks in the southern Coast Ranges is undoubtedly the equivalent of those on San Pablo Bay, the latter name will be extended to it. In the San Luis Obispo region the nonconformity of this series of rocks with the Monterey series is distinctly shown in many places. Good examples appear along the coast north of Pismo as well as in the vicinity of Santa Margarita in the upper Salinas Valley. The basal conglomerates of the San Pablo formation, often but little disturbed, lap over on the more highly tilted and disturbed shales and contain many fragments of the latter often filled with mollusk borings. A great interval of time must have separated the deposition of the San Pablo formation from that of the bituminous shales, for the former formation extends over the shales in places and rests directly on the Golden Gate series. This time must have been sufficient for the erosion of at least 5000 feet of the Monterey series. During this time also the chief chemical change was wrought in the bituminous shales, for pebbles of the flinty altered shales occur at the base of the San Pablo formation in exactly the same condition as the shales on which this formation rests.

The discovery by Dr. Merriam of the marked palæontologic differentiation of the fauna of this group of rocks is an important addition to our knowledge of the younger formations of the Coast Ranges. That it is not a local condition is shown by the results reached by the writer along different lines and wholly independently. The pronounced nonconformity so clearly apparent in the San Luis Obispo region is confirmatory of the palæontologic investigations and firmly establishes the validity of the new formation. Its fauna is certainly older than that of the Merced beds, and if it should prove to be the uppermost Miocene the rocks of that age in California can no longer be looked upon as forming a unit but separated into two divisions by an extended period of elevation and erosion. This point established other and puzzling questions relating to the Miocene and Pliocene are in a fair way to be cleared up.

Paso Robles formation.—The later Neocene in this portion of the Coast Ranges consists of a very extensive series of beds having apparently a fresh-water origin. They fill the Salinas Valley as far up as Atascadero, lapping over unconformably upon the upturned and sharply folded San Pablo formation. They are characteristically exposed about the town of Paso Robles, hence the designation. From Paso Robles the beds extend westward toward the Santa Lucia Mountains, and for many miles north and east of that place, filling the valley of the Estrella and its tributaries, and may reach into the Great Valley. The formation consists of conglomerates, sandy and marly clays, as a general thing, but slightly consolidated. The great extent of this formation in the drainage area of the upper Salinas River, its peculiar character and total absence of marine organisms, or organisms of any kind as far as observed, make it appear probable that it is of fresh-water origin, and for these reasons, though it is possibly contemporanous with the marine formation known as the Merced beds, it should be given a distinct name. The strata are generally almost horizontal, but along the Salinas River in particular they are tilted and faulted. Beds of the same character overlie the San Pablo formation in the vicinity of Arroyo Grande.

Fresh-water beds of Pliocene age are widely distributed through the Coast Ranges.[1] Those in the valleys of the upper San Benito and Salinas have been referred to by Lawson as Pliocene delta deposits,[2] and considered the equivalent of the Merced beds. While the latter view is probably correct, there is no reason to consider them delta deposits; on the contrary, they have decidedly the character of fresh-water lake beds, and there is no reason to believe that they were ever connected with the Merced beds.

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[1] Monograph No. XIII, U. S. G. S., p. 238; Bull. Dept. of Geol., Univ. of Cal., Vol. I, p. 152; Bull. Dept. of Geol., Univ. of Cal., Vol. I, p. 363.

[2] Bull. Dept. of Geol., Univ. Cal., Vol. I, p. 153.

PLEISTOCENE.

Under this designation are included the terrace formations, blown sand, stream gravels, and alluvial bottoms. These were not all formed at once, but represent a complicated history. The terrace formations belong to the oldest division. The most extensive area included under this head embraces a great stretch of sandy mesas and hills between the mouth of the Arroyo-Grande Creek and the Santa Maria River.

The coast, almost everywhere more or less distinctly terraced, forms an elevation of about ten feet above mean tide up to 750 feet. In addition terrace-like effects were noted upon the southern slope of the Santa Lucia range at elevations of 1000, 1400, and 1700 feet, aneroid measurements. In many places along the upper Salinas there are beautiful examples of river terraces cut upon the Paso Robles formation.

IGNEOUS ROCKS.

The igneous rocks of the San Luis Obispo region form one of the most interesting features of that field. Intrusives and surface flows are numerous, especially the former. They are so abundant in the Golden Gate series as in many places to form fully one-third of the surface exposures. The extensive sheets of diabase and peridotite appeared during the Cretaceous, and a great variety, though of much lesser extent, during the Miocene. The age of the andesite and dacite granophyre forming the buttes reaching from San Luis Obispo to Morro Bay cannot be determined with certainty. It certainly antedates the peridotites which appeared at the close of the Knoxville and may be of pre-Cretaceous age.

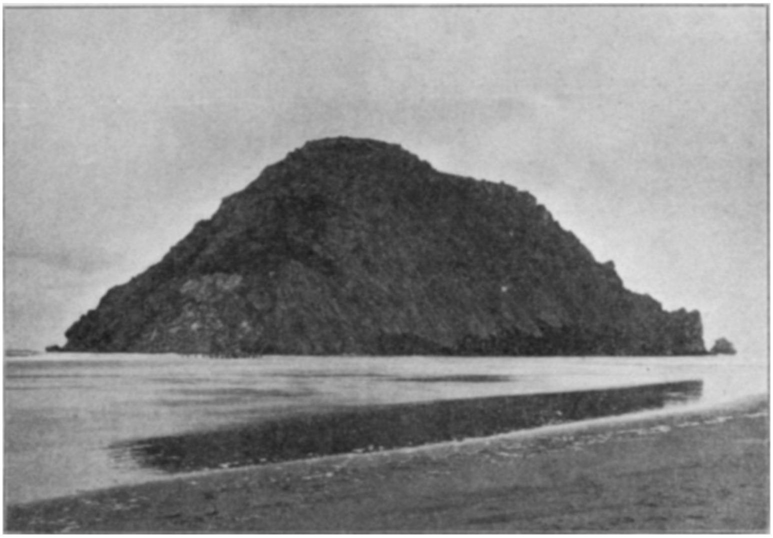
The igneous rocks, all taken together, show a great range in chemical and mineralogical composition, with examples of rare and interesting types. They have not yet been thoroughly studied, and no detailed description will be attempted in the present paper.

In the following outline the main types of igneous rocks occurring in this field will be given and arranged in groups according to age:

Granite,	Earlier than the Jurassic.
Basalt, intrusives and surface flows, Peridotite, Diabase,	Earlier than the Cretaceous. Intrusive in Golden Gate series.
Dacite granophyre, Andesite granophyre,	Earlier than the Middle Cretaceous. Possibly pre-Cretaceous. Intrusive in Golden Gate series.
Diabase,	Earlier than the Chico. Intrusive in Knoxville beds.
Peridotite serpentine and related feldspathic rocks, including diabase, gabbro, and pyroxenite,	Earlier than the Chico. Intrusive in the Knoxville and preceding diabase.
Rhyolite, Augite teschenite, and olivine diabase, Quartz basalt, Basalt,	All probably earlier than San Pablo formation. Intrusive in Monterey series.

The granite covers a large extent of country east of the upper Salinas River. It is remarkably uniform, consisting of quartz, biotite, orthoclase, plagioclase, and titantite. Large orthoclase phenocrysts give a porphyritic aspect in places. Numerous dikes of a finer-grained granite intersect it. Nothing is known concerning the age of the granite, save that it forms the southeastern continuation of the crystalline axis of western Monterey county, on which the Golden Gate series rests with a basal conglomerate. It is certainly much older than the Jurassic.

The dikes of basic pre-Cretaceous intrusives in the Golden Gate series are almost innumerable, and, as they are generally much altered, weather away readily and are difficult to map accurately. Owing to the disturbances which the series has undergone, it is also almost impossible to distinguish in all cases the surface basalts from the dikes with similar appearance. The greater number of the dikes are fine grained and amygdaloidal on the edges. Dikes of diabase are also numerous. The rock having the most limited distribution is the peridotite. This is not as much decomposed as might be expected, considering its age, and consists of olivine, a rhombic pyroxene, and sometimes augite and a little feldspar. The dikes follow the strike of the rocks, and are more abundant in the jasper horizons. Contemporaneous flows were not recognized with certainty, and it is the writer's opinion that they are more rare upon the San Francisco peninsula than Lawson has supposed. They are not all of the same age. The surface flows did not take place until after the Golden Gate series had been upturned and planed off. This is shown in the hills east of Los Osos Valley.



Morro Rock (dacite granophyre) on the coast at mouth of Morro Bay.

The dacite and andesite granophyres are strikingly interesting rocks. The occur as roundish or lenticular plugs forming the large buttes, besides many small ones, between San Luis Obispo and Morro Bay. The dacite variety is confined to several of the northern ones, the andesite to those nearer San Luis Obispo. The important constituents of the former are quartz, biotite, and an acid plagioclase feldspar ; of the latter labradorite, biotite, and enstatite, as porphyritic constituents in a granular base. Morro Rock is the most .striking topographic feature on the coast of California.

The diabase intrusive in the Knoxville beds has a character different from any other rocks in the region under investigation. It is grayish in color, fine grained, and amygdaloidal upon the edges. It has come up in great dikes or sheets on either side of the main Knoxville area, throwing the latter into a synclinal trough. It extends northwest from Cuesta Pass for many miles, and is quite uniform save for local gabbroitic variations.

The peridotites and related feldspathic rocks of the Coast Ranges are well known. The great body of this rock in the San Luis Obispo region has been changed to serpentine. It consisted originally of olivine and augite. Local variations rich in feldspar occur along the Santa Lucia range forming diabase and gabbro. The feldspathic facies is quite extensively developed not only upon the borders of the great serpentine area north of San Luis Opispo, but also in many places as apparently independent intrusions. From their similarity in character it is easy to see, however, that all these rocks are genetically related. The serpentine has the usual sheet or lense-like character conformable to the dip and strike of the inclosing rocks, which usually stand very steeply.

The igneous rocks of Tertiary age have a great range in chemical and mineralogical composition. The succession of these rocks was only partly determined. The oldest is the rhyolite of which there are two varieties. One contains free quarts and occurs as a very limited surface flow, being mostly represented by tuffs. The other has the form of long, narrow sheets intruded near the base of the Miocene, and contains no free quartz, but an abundance of plagioclase phenocrysts. The ash which is so widespread at this horizon appears to be connected with rhyolite eruptions, but these particular sheets are probably of later date, as they are clearly not surface flows. The ash reaches in places a thickness of many hundreds of feet, and in the hills south of San Luis Obispo passes downward into an agglomerate of bowlders of perlitic glass, many of them of large size.

The surface flow of rhyolite on Old Creek is very interesting. It is only a few feet in thickness and imbedded in a great mass of tuffs of the same character. The sheet terminates at one edge in flattened nodular masses from one-half inch to eight inches in diameter. Some of these are entirely free, others more or less connected in the plane of flow. Superficially many of these nodules appear like concretions or large spherulites, but their internal character is entirely different. The flowage lines pass through them regularly without regard to the shape of the surface, and the interior appears to have shrunken away from the center, from which radiating cracks either empty or filled with chalcedony spread toward the outside. These cracks break across the banding with but little disturbance of the latter. They do not appear to be real spherulites and the field relations suggest that their peculiar character may be due to sudden cooling under water.

The augite teschenite and olivine diabase form two generally distinct variations of one magma. The former rock contains varying proportions of analcite and its alteration products, augite and a basic feldspar. The typical examples are rather light colored rocks, but with the appearance of olivine and a decrease of feldspar and analcite the rock becomes very dark and basic looking. Some of the olivine diabase contains so little feldspar that it might with almost as much propriety be termed a peridotite. These rocks are among the most interesting of any yet discovered in the Coast Ranges, and as far as is yet known the augite-teschenite is confined to Santa Barbara and San Luis Obispo counties. It has been described in former papers.[1] Not only is it petrographically interesting, but remarkable for its structural relations to the Miocene in which it is intruded.

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[1] Bull. Depart. of Geol., Univ. of Cal., Vol. I, p. 273; *ibid.*, Vol. II, p. 19.

The quartz basalt occurs in the form of dikes intruded at the base of the Miocene east of Edna. The larger one is nearly continuous, following the strike of the rocks for two and one-half miles. The rock is dark and fine grained with a few scattering phenocrysts of labradorite feldspar. The most important phenocrysts are quartz scattered in a fairly uniform manner through the rock. The quartz grains show the effects of corrosion and are surrounded by augite microlites. The analysis shows that the rock has a rather low percentage of lime, but there can be no doubt that it belongs among the basalts.

Other Tertiary basalts occur on a small scale at several different points, but they have no striking features and will not be described here. It is impossible to determine the relative ages of these basic igneous rocks, although it would seem that with the exception of the rhyolite they followed the disturbances which folded the Miocene.

STRUCTURAL GEOLOGY.

Nearly all the structural features have a linear arrangement along northwest and southeast lines. The mountains are structurally synclines elevated by comparatively recent movements, the most important being faulting. This region may be divided in a general way into five crustal blocks, as follows, beginning on the north: the granite and associated rocks north of the Salinas Valley, the depression occupied by the Salinas Valley, the Santa Lucia range, the western foothills of this range and the broad valleys at its southern base, and last, the San Luis range. Each of these blocks has behaved as a unit since Miocene, or in several cases very much earlier times. All the faulting now recognizable dates from later Neocene time. The Santa Lucia range constitutes a remarkable fault block. It has been elevated, not by a single fault on each side, but in most places by several forming step faults. A fault line follows the lowest portion of the Salinas Valley, and other lines of folding and faulting are to be seen along the northern slope of the Buchon range.

One of the most striking structural features is the occurrence in the Monterey shales of the Buchon range of great bodies of bituminized sand forced into its present position during the folding which terminated the deposition of the San Pablo formation. There are two of these sand pockets or bosses north of Sycamore Springs. They occur near the ends of subordinate anticlinal folds. The largest body of sand is fully 500 feet across, elongated somewhat in the direction of the strike of the shales and with narrow dikes radiating from it. The sand has probably been forced in from beneath from the adjoining San Pablo formation, as the nose-shaped terminations of the anticlines in which the sand appears have been forced slightly over that formation.

The structural relations of some of the igneous rocks are quite remarkable. Especially is this true of those which have appeared in the Monterey series. Bodies of the teschenite and olivine diabase magmas have come up underneath this series but have rarely if ever broken completely through it. Having penetrated as far upward as the limestones or bituminous shales they have spread out between the strata in sheet form. Two remarkable cases occur north of San Luis Obispo between it and the railroad water tanks. Here are two hills, one a half mile in diameter, the other nearly a mile, rising quite abruptly from the lower rolling country and capped by a thin layer of Monterey limestone and shale. Each hill has an amphitheater-like center, the strata dipping inward from all sides but one, and from this a depression has been eroded. The peculiar topography and saucer-like structure is due in each case to a sheet of teschenite which outcrops around the steep outer slope metamorphosing the overlying rocks. From a general study of the region it seems likely that the Monterey series had already undergone disturbance and folding when these igneous rocks appeared.

One of the crests of the Santa Lucia range about 20 miles north of San Luis Obispo has on its summit a long narrow remnant of Monterey shales folded in synclinal form. For some miles the center of this syncline has been broken through by bodies of olivine diabase. They appear as dikes or bunches which as exposed in places have lifted up and inclosed large masses of the shale.

On Old Creek there are very large sheets of the diabase, from the upper surface of which the Monterey shales have been nearly removed, as they occur only in patches here and there. These igneous masses in many respects resemble laccolites, only that instead of having arched the strata in dome form they appear as saucer-shaped sheets issuing from lines of fracture along centers of synclines.

GEOLOGICAL HISTORY.

The geological history of this region is exceedingly complicated, and in the short review following only the merest outline can be given. The earliest event of which we have any record in the Coast Ranges was the invasion of the crust by great masses of molten granite, metamorphosing the existing sediments to marbles and schists. The date of this convulsion is unknown save that it must have long antedated the Jurassic. With the beginning of the deposition of the Golden Gate series the great area of crystalline rocks which had for so long a time formed a land mass in the region of the present Coast Ranges began to subside and continued to do so with oscillatory movements until its close. Although this formation is so widespread it is essentially a near shore or shallow water formation as it consists so largely of sandstone. The conditions at times changed and the sea bottom instead of being subjected to sedimentation from the land was covered with the siliceous skeletons of radiolaria which it is believed form the main portion of the lenticular jasper beds.

With the upheaval of the series, and in some cases possibly earlier, appeared dikes and sheets of basic igneous rocks which everywhere so abundantly characterize it. After erosion had planed off the surface flows of basalt took place.

The period of the intrusion of the more acid plugs forming the line of buttes between San Luis Obispo and Morro Bay is not exactly known. It may have taken place before the deposition of the Knoxville beds.

With the beginning of the Cretaceous the Coast Range region sank and the thin bedded sandstones and dark shales of Knoxville age were formed. They lie unconformably upon the upturned strata of the Golden Gate series and their basic intrusives.

At the close of the Knoxville a disturbance not heretofore recognized in the Coast Ranges took place and the great masses of diabase were formed which threw the beds of that age along the Santa Lucia into a synclinal form. Before the beginning of the Chico another important event took place. This was the welling up of vast bodies of peridotite, now altered to serpentine, which appear everywhere in the Coast Ranges in rocks older than the Chico. Dikes of serpentine penetrate the diabase just referred to and are therefore younger. It is then clear that the conglomerate at the base of the Chico and the nonconformity of this formation upon the Knoxville is due to a widespread disturbance resulting in an elevation of the region above the sea during a portion of the Middle Cretaceous.

The Eocene is absent from this portion of the Coast Ranges and it is legitimate to infer that the region was above water during the whole period.

Before the inauguration of the Neocene sinking commenced, and we find rocks of this period everywhere underlaid by a conglomerate formed as the sea encroached upon the land. Shortly after the beginning of the deposition of the Monterey series violent volcanic disturbances are recorded as having taken place. Local flows of rhyolite occurred and ash of that composition in the form of glass was thrown out in vast quantities and distributed over the sea for many miles. Following this the bituminous shales and limestones were formed. They consist almost wholly of organic material, the more or less blended and broken skeletons of foraminifera, diatoms, and radiolaria. A very extended period of time must have been required for the deposition of 5000 feet of these sediments which are believed to accumulate slowly. Peculiar conditions must have existed, the sea being practically free from detrital material though the area of deposition could not have been far removed from the land.

The latest igneous action in this region probably followed the initial folding of the Monterey series preceding the deposition of the San Pablo formation, when the basalt, teschenite, and olivine diabase appeared.

After a period of elevation and prolonged erosion during which the great thickness of Monterey series was totally removed from some areas, and the shales of that period had undergone a chemical change, a subsidance began and the sandy strata of the San Pablo formation were laid down. The present configuration did not exist and this formation probably spread across the Santa Lucia range.

The discovery of the nonconformity of the San Pablo formation upon the bituminous shales (Monterey series) necessitates the addition of a correction to the diagram recently published illustrating the oscillations of the Coast Ranges.[1] Two oscillations should appear where the one is represented as separating the Miocene and Pliocene, with the understanding that the dividing line between these two periods is not at present settled.

After a deposition of at least 3000 feet of sediments, elevation and folding were experienced, terminating the San Pablo period; and the outlines of the present mountains were originated.

Marine formations of late Neocene age have not with certainty been recognized in this region. The Paso Robles formation indicates the existence of fresh-water lakes of large extent. With the close of the Neocene an upward movement was inaugurated and continued, it is believed, until the region was much higher than at present.

Following this early Pleistocene elevation a reversal took place and sinking went on until the coast was submerged to the depth of the highest terraces. With the gradual recovery from this depression the lower terraces were formed and again a point was reached somewhat above the present. How much this was is not known for the mouths of all streams have been flooded by the ocean. The last movement has been one of subsidance as shown not only by the flooded stream mouths but by Morro Bay, a sheet of water whose origin can only be accounted for by the theory of a depression.

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[1] American Geologist, Vol. XX, p. 225.

It is hoped that the foregoing discussion will convey some conception of the interesting and complicated problems encountered in the geology of the Coast Ranges.

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